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Subject: Letter Progress Report of Work ~~under~~ Contract No. NASr-54(06) for the Period 1 December 1966 to 28 February 1967

Gentlemen:

This status report covers work during the period from 1 December 1966 to 28 February, 1967 under Contract No. NASr 54(06), Man-Machine Performance Measurements. By the end of this period approximately 90% of the budgeted funds for the full three-year period have been expended.

We are continuing to conduct and analyze experimental studies of human performance characteristics in manual control tasks, and to develop techniques for manual control system simulation and analysis.

1. EXPERIMENTAL STUDIES

Human Operator Performance with Predictable Input Signals

Computation of Error Power Spectra was completed in Experiments 66-5, 66-6, and 66-7 that were designed to examine the source and characteristics of the remnant noise observed in the operators output in earlier work. An abstract that describes the initial results of experiment 66-5 and 66-6 that has been submitted for presentation at the 8th Annual Symposium on Human Factors in Electronics, Palo Alto, California in May is included as Appendix I of this Progress Report.

Operator Performance in Two-State Relay Control Systems

In Experiment 66-1, described in earlier progress report (see, for example, Progress Report dated July 11, 1966 for period 1 March 1966-31 May 1966) the ability of skilled drummers to monitor and control an ongoing response process at two or more levels simultaneously was assessed by requiring control of externally introduced sine and triangular wave input signals with a two-state relay control system. It was observed that the operator's performance was so good that little was revealed about the dynamics of higher level control processes. As a follow-up to that research Experiment 67-1 has been designed and data collection is underway. In this study some of the same subjects that served in 66-1 have been recalled, and after a brief retention test, have performed essentially the same task, but with externally introduced discrete step inputs occurring at random times during each 30-second trial. It is hypothesized that the operator's transient response to unpredictable steps will permit the kinds of analysis of higher level dynamic performance that were not possible in the earlier study.

Operator Performance Enhancement by Force Feedback Compensation

Research is continuing on the evaluation of the usefulness of the feedback compensation technique as described in the previous Progress Report. Current work is focusing on exploratory studies to determine the range of plant dynamics over which the approach appears feasible and useful. The abstract of a report on this project to be presented at the USC-NASA Annual Working Conference on Manual Control is included in this Progress Report as Appendix II.

Regression Analysis

A method has been developed for solving multiple regression analysis problems using an analog computer. This technique has been successfully applied to the determination of parameter values for a model of the human controller. Accurate values of both constant and slowly varying parameters have been obtained using as little as two seconds of data. Work is continuing on application of this technique to noisy models.

Related Activities

A proposal for a three year continuation of project work beginning 1 July 1967 entitled, "Analysis and Synthesis of Manual Control Systems" was submitted to NASA-OART in January 1967.

2. PERSONNEL

During this reporting period the following people have charged time to the subject contract:

L.E. Fogarty	.50	G. Johnson	.25
R.M. Howe	.10	E. King-Smith	.50
A. Burgett	.15	J. Overmars	.25
J. Duffendack	.25	R. Rapley	.50

L.K. Fensch	1.00	M. Rash	.33
J. Herzog	.50	J. Warner	.50
G. Jackson	.50		

Sincerely yours,

Robert M Howe

Robert M. Howe
Information and Control Engineering
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Richard W. Pew

Richard W. Pew
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Department of Psychology

Co-Principal Investigators

Enclosures

Appendix I

HUMAN OPERATOR OUTPUT NOISE: CENTRAL VS. PERIPHERAL PERFORMANCE LIMITATION

Richard W. Pew, John C. Duffendack, and Linda K. Fensch

Empirical data on operator performance in time delay systems suggested the hypothesis that the fundamental characteristics of the neuromuscular control system should be regarded as a discrete signal processing system in which the motor system generates discrete impulsive changes in force at a maximum rate of 6.6 pulses per sec. This rate limit appears to be set by central timing limitations and corresponds to a cycle time of 200 msec., believed to be the time for one complete cycle from sensory input to motor command.

In a previous paper (1), we have reported on the spectral characteristics of a noise component in the output of a human operator in a manual control system. In a typical experiment the operator was required to track a slowly varying sinusoidal input signal (0.10 Hz) with an arm controller using either a pursuit or compensatory display. Spectral analysis of the error velocity signal revealed a broad peak of power uncorrelated with the input signal in the range of 0.5 to 2.0 cycles per sec.

In the first experiment of the current series, the operator performed compensatory tracking of sine waves with a transport delay added to the forward control loop immediately following the control stick. Delay durations of 0, 0.18, 0.36, 0.72, and 1.44 sec. were studied. Analysis of error velocity power spectra under these conditions revealed systematic changes in the shape of the power spectrum as a function of the amount of delay. For delays of 0.18 sec. or greater two peaks in the noise distribution could be identified, and the position of these peaks shifted downward in frequency in an orderly way as a function of the amount of external delay introduced.

These results argue that the characteristics of man's output noise are influenced by central processing factors since the introduction of time delay has no direct effect on the peripheral motor system. Only the visual input to the operator was changed. It was noted that in every case the two peaks stood in a 1:3 harmonic frequency relationship to each other and it was hypothesized that these peaks might be the primary terms of the Fourier representation of a symmetric waveform, such as a square or triangular wave. Such a waveform would be produced by the "move and wait" strategy that has been suggested by other authors for control of time-delay signals. When the period of this waveform was assumed to result from the sum of man's central processing delay, together with the lag associated with the dynamics of the arm and control stick and with the external time delay, estimates of man's internal delay were in the range of 150-350 msec. This range seems consistent with similar estimates derived from discrete signal processing tasks.

In a second study the sine wave tracking experiment without time delay was replicated with a force (isometric) control stick. Since the effect of arm dynamics and the control stick dynamics are minimized under these conditions, it was possible to examine the noise spectrum relatively uncontaminated by these factors. The resultant power spectrum again revealed two pronounced peaks, identifiable as fundamental and third harmonic, that compared closely to the shapes of the spectra derived from the time delay experiment. In the force stick spectra, the fundamental peak was estimated to occur at 3.1 Hz and the third harmonic at 9.3 Hz. One-half cycle of the fundamental corresponded to a period of 150 msec., representative of man's internal time delay, and the third harmonic would probably be regarded by physiologists as a typical voluntary tremor frequency.

A third experiment, studying control of time delay systems with an isometric control device, is in progress, but our working hypothesis is that the neuromuscular system is driven by discrete impulsive changes in force output at a maximum rate corresponding to the period of 200 msec. (5 pulses per sec.), and that this rate limit is set by fundamental central processing and transmission delays—rather than strictly peripherally. We never see the discrete symmetric waveform outputs because of the heavy filtering of the neuromuscular response above 10 Hz due to the mass of the muscle system, the arm and the typical control device.

Reference

1. Pew, R.W., J.C. Duffendack, and L.K. Fensch, "Sine Wave Tracking Revisited," IEEE Transactions on Human Factors in Electronics. (In Press)

Appendix II

FORCE FEEDBACK COMPENSATION: A NEW CONCEPT FOR IMPROVED MANUAL CONTROL SYSTEM PERFORMANCE

James H. Herzog and Richard W. Pew

In a previous study Notterman and Page (1962) compared tracking performance between two equivalent dynamic systems. In one case the dynamics were represented in mechanical form on the control stick, but in the other case the dynamics were simulated on an analog computer. They found system performance was uniformly better in the case of on-stick dynamics that the operator could feel. We believe that this principle may be generalized to the case in which the plant dynamics are not directly represented in mechanical terms by utilizing a force feedback compensation system that restores the correspondence between the mechanical feel of the control stick and the actual plant dynamics. In order to acomplish this a mechanical analog of the differential equation describing the plant is implemented on the control stick. Then instead of using the control stick output position as the control variable applied to the plant, a signal proportional to the operator's output torque is employed. This effectively provides the appropriate mechanical feel characteristics without adding additional dynamic filtering in the forward loop.

This technique of force feedback compensation has been evaluated for the case of control of a lightly-damped second-order system. When the performance with the compensated system was compared to that of an isometric stick with analog plant dynamics, the compensated system was better by a factor of two to three. The difference was not reduced by extended practice with the two systems. It is believed that this concept has applicability in a number of areas of manual control. The technical seems especially suitable for complex plants where the benefit of supplementary sensory information can greatly improve performance.

Reference

Notterman, J.M., and Page, D.E., "Evaluation of Mathematically Equivalent Tracking Systems," Perceptual and Motor Skills, 1962, 15, 683-716.